The Effect of Redundancy on Video Broadcasting in Vehicular Networks

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Abstract—Advancements in on-board and wireless communication technologies provide the backbone for the deployment of a wireless network among vehicles. Most of the envisioned applications would offer enhanced services if multimedia support is provided. However, there are several challenges on the exchange of multimedia data at suitable levels of quality.

In this work, we analyze video broadcasting which is a specific multimedia functionality necessary to a wide variety of applications. Particularly, we discuss and evaluate the role of redundancy in improving this mechanism. We have verified that although redundancy increases video broadcasting effectiveness, coding techniques do not improve redundancy’s efficiency.

I. INTRODUCTION

The continuous advancements in both vehicular and communication technologies have provided the necessary support to the deployment of a new network, namely Vehicular Ad Hoc Network (VANET). This network consists on the scenario where moving vehicles are connected through wireless exchange of messages among mutually reachable vehicles. The communication between vehicles is performed by radios with short range as defined by the Dedicated Short-Range Communications (DSRC) standard [1].

Although a VANET is a specific type of Mobile Ad Hoc Network (MANET), it has its own characteristics with distinct restrictions and challenges. Hardware limitations are considerably less restrictive, since vehicles carry computational devices much more powerful than the ones in common MANETs (e.g. palm tops, cellphones) and, mostly important, VANETs’ devices have a persistent source of energy. However, nodes in VANET move at higher speeds which increases substantially the network’s dynamism. In summary, VANETs do not suffer of resources restriction, nevertheless, they have a highly dynamic topology.

VANETs provide the necessary environment for the deployment of several interesting applications. These applications may automate many of the routine procedures within roads and urban traffic, enhance safety, improve emergency response or entertain passengers. The majority of these applications benefit if multimedia support is offered. For example, emergency responders would have access to videos from accidents sites while they are still on their way there.

In this work, we focus on applications that require in loco cameras to broadcast captured video to many (or even all) vehicles in the network. Through this service, drivers and passengers would be able to visualize road and traffic conditions ahead and take informed decisions regarding safer or faster routes. This application supports reasonable latency levels, nevertheless it requires that the network handles efficiently data broadcast in order to achieve high delivery ratios.

We have conjecture three hypotheses and we have evaluated them. We have first assumed that dissemination techniques common to MANETs are unsuitable to VANETs. Then, we have considered that additional redundancy improves broadcasts’ performance. Finally, we have presumed that using Erasure Coding would increase redundancy’s efficiency. As the remainder of this article shows, while the first two conjectures are proven to be true, the last is showed to be a fallacy.

We discuss further each hypothesis in the following three sections. In Section V, we compare our results with existing works in the literature. Finally, in Section VI, we summarize our findings and we address future directions.

II. TRADITIONAL TECHNIQUES ARE NOT SUITABLE

It is often required that information is disseminated in mobile networks. The information shared throughout the network ranges from simple alerts to rich data such as video frames. The common techniques for this purpose focus mainly on limiting the overhead of messages with little focus on delivery ratio since high rates are easily achieved.

The most common solutions are Flooding or its variation Gossiping [2]. Flooding is the most simple approach where the source broadcasts the information and every receiver forwards it again with a subsequent broadcast. Gossiping follows the same concept, however, intermediary nodes do not always rebroadcast the received information but instead only do it within a predefined probability.

For traditional MANETs, flooding is the most effective manner of reaching all nodes in the network. Nevertheless, it is not efficient since many of the rebroadcasts are fully redundant and do not reach any uncovered node. Therefore, in these scenarios, Gossiping exploit better the trade-off between number of transmissions (cost) and reachability (benefit). However, these solutions are only suitable for a scenario where the network is mostly connect and its topology is not as dynamic as in VANETs. It is notably challenging to achieve

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high delivery ratios on data dissemination in VANETs and this causes a significant change of perspective. Before, the overhead cost of excessive broadcasts was focused, now, the main goal is in reaching a larger number of nodes.

Based on all this, we define our first hypothesis:

**Hypothesis 1:** Traditional dissemination techniques are not suitable to video broadcast in VANETs.

### Empirical Evaluation and Results

Throughout this work, all our evaluation is conducted through simulations using the Network Simulator 2[3]. We have used the Two Ray Ground propagation mode and there was no routing algorithm, all transmissions are broadcasts. Each vehicle had a communication radius of 100 meters. Each plotted result is an confidence interval at a confidence level of 95% and an average from 32 distinct runs which permitted us to use the normal distribution for such calculations.

The scenario that we have envisioned to verify our hypotheses is a 10 km segment of a highway where a camera is in the middle of it and broadcasts a 1.3MB video through packets with a maximum payload of 1000 bytes, thus, at least 1300 unique packets must be sent by the source. In order to simulate such environment, we have used the Freeway+ Mobility Model [4] with 3 lanes in each of the two opposing directions with speeds varying from 5 to 40m/s (with different ranges for each lane). The density is of 50 nodes/km and two extra km were added (one in each end) in order to avoid results biased from vehicles reaching the road extremes (extra nodes were also added to maintain density but no exchange of data is conducted in these extra kms). This scenario is used for the evaluation of the other hypotheses as well.

This approach was simply implemented as a succession of broadcasts. Gossiping is implemented using the camera as the source node of packets which broadcast to all the vehicles in its vicinity. Whenever a node receives a packet for the first time, it re-broadcasts the packet within a pre-defined probability $p$. Flooding is a specific case of Gossiping with $p = 1$.

Throughout this article, we use a metric to measure the effectiveness of each approach. This measure is the percentage of the broadcast video that was received by a vehicle. We calculate it by comparing the stream of bits received with the original video broadcast. We named this metric as **correctness** and it is showed in graphs as an average of either all nodes or the specified set of nodes.

In Figure 1(a), we have plotted the most relevant information regarding Hypothesis 1 for different values of $p$. It is shown the achieved correctness in two different ways. The first one is the average of all nodes in the network and it is clear that it is extremely low.

However, a more appropriate way of analyzing this solution is looking into the correctness of nodes grouped based on their distance to the camera\(^1\). That is what is shown on the second curve using $p = 50\%$. We can see that a much higher correctness is achieved by vehicles closer to the camera and, besides that, the curve follows a steep decline with longer distances. Although the cost curve grows in an exponential fashion, it is still not excessive since the broadcast is limited to nodes close to the camera.

Our first hypothesis states that the existing most effective (not necessarily efficient) protocols for data dissemination in MANETs are not suitable to VANETs. We have evaluated the performance of Gossiping and Flooding in a highway scenario.

The mean correctness of the whole network is extremely low achieving at most ratios just higher than 10%. This is certainly an unacceptable rate for the reproduction of any video. However, when this same metric is used for vehicles within sectors limited by their distance to the camera, we can see that vehicles closer to the source of the video reach much higher correctness rates. These rates are still not reasonable but it does represent better the behavior of the protocol. It is clear that any dissemination mechanism has to struggle to reach vehicles outside of the video source vicinity.

In terms of transmission costs, we have observed that there were not excessive number of packets sent but this is not due to the fact that messages were exchange only within short distances to the camera.

Therefore, Hypothesis I has been corroborated.

### III. Redundancy Increases Delivery Ratio

In general MANETs, Gossiping is used alternatively to Flooding in order to avoid unnecessary transmissions of content already received by its neighbors. The main concept in this approach is to avoid redundant packages maintaining high delivery ratios.

Redundancy has the opposite role in VANETs since wide reachability requires much more effort. In constantly disconnected but also dynamic scenarios, the reception of duplicated content may lead to transmissions to nodes previously unreached. This happens since such packages can follow paths different from the previously ones used. These different paths are created either by the transmission through links that were congested before or links that are now available due to nodes movement. An important advantage of using redundancy is that it is a mechanism for handling path breaks or any unsuccessful transmission that does not require acknowledgments sent back by receivers. Besides that, it is particularly suitable to dissemination since checking if vehicles have successfully received the content is unfeasible.

Therefore, our second hypothesis is:

**Hypothesis 2:** Redundancy increases delivery ratio of video dissemination in VANETs.

### Empirical Evaluation and Results

Redundancy can be implemented in two different fronts: at the source; and at intermediary nodes. In this work, at the source, we have replicated outgoing packets in a way that any original unique packet generates $r$ copies that are sent one after the other. Therefore, each unique segment of data that incurs into a new frame generates $r+1$ outgoing packets that
are sent in sequence (with the same sequence number so they are not handled as packets with different content).

However, we have noticed that making use of a redundancy approach focused solely on the source is not sufficient to achieve its potential. Therefore, we have also used redundancy generated at intermediary vehicles. This is implemented through a mechanism that with half the frequency of broadcasts, with a probability \( P(d) \), an intermediary vehicle restarts a dissemination of a previously received packet.

Redundancy at intermediary nodes works through a series of measures. First of all, whenever a vehicle receives a packet with a sequence number it has not received yet, before forwarding it, the node stores the packet in a buffer. With half the frequency of outgoing packets at the source, a mechanism is triggered where it decides if the oldest packet in the buffer should be disseminated again or not. This decision is done taking into consideration the probability function of a rebroadcast \( P(d) \), where \( d \) is the distance between the vehicle itself to the camera source of the video content. It is defined as: \( P(d) = 0.25 \cdot 1/(2^d/1000) \).

If the stored packet is disseminated once again, the receivers proceed normally as if it is a dissemination started at the source. Therefore, it checks if it has received the packet before (based on the sequence number), if not, the vehicle stores the packet in its own buffer and forwards it respecting the Gossiping probability \( p \).

The decision to have \( P \) as a function of the distance between vehicles and the video source is due to the characteristics of applications that require video dissemination throughout a VANET. It is clear that vehicles closer to the camera are more interested in the captured video than farther ones. It is unlikely that vehicles at great distances would have enough interest on the content of the video to compensate the overhead in flooding the network up to regions far from the video source.

In Figure 1(b), we have plotted results for this approach with \( p = 50\% \). Each curve represents the behavior for different number of copies \( r \). We can observe that for short distances from the camera, initial increases on \( r \) result in higher correctness ratios, however, further increases lead to lower rates. For all values of \( r \), there is a steep decline on correctness as farther vehicles are from the camera. Nevertheless, higher values of \( r \) have a less steep decline than lower ones.

Figure 1(d) shows the achieved correctness for different Gossiping Probabilities for vehicles within 500 meters from the source camera. The curve of values when there is no forced additional redundancy (in both source and intermediary nodes) exhibits a oscillating behavior by initial increases on \( r \) leading to higher correctness until it reaches a peak and further increases lead to lower correctness rates. When we pay closer attention to the results with \( p \) greater than 70\%, we can see that the same behavior happens in the curves with forced additional redundancy as well.

In terms of overhead, we can see in Figure 1(c) that independently of the value of \( r \) used, the number of packets sent increases exponentially with increases on the Gossiping probability \( p \). Besides that, we can observe that increases on \( r \) lead to linear increases on the number of packets sent.

In this section, we test the Hypothesis 2, which states that forced additional redundancy increases video dissemination effectiveness. Besides its effectiveness as delivery ratio (i.e. correctness in this article), we have also evaluate its efficient based on the overhead as the total number of packets sent.
Although we have not plotted the average correctness independently of distance to the camera (lack of space), we have observed that adding redundancy does increase the overall mean correctness in the network (Figure 1(b) can be used to support that - at least for \( p = 0.5 \)). However, the noticeable improvements in correctness for initially higher values of \( r \) are not sustainable with further increases in \( r \). When more than 10 copies of the same packet is sent by the source (\( r > 9 \)), the linear increase on overhead persists but it does not reflect in better results in terms of correctness.

Another interesting observation based on results in Figure 1(b) is that higher values of \( r \) lead to higher correctness rates at vehicles far from the source camera but not necessarily at closer vehicles. Correctness at nodes close to the camera is also negatively affected by higher Gossiping probabilities of forwarding \( p \) (see Figure 1(d)). This happens due to the increasing traffic and consequently congestion that higher values of \( r \) and \( p \) cause. Therefore, the manipulation of these parameters can be done depending if the main goal is to achieve higher correctness rates at vehicles closer to the camera or a broader reachability within the whole network.

The large number of packets sent is the expected result since much more nodes are reached and involved in the video dissemination. Besides that, it is clear that although more repetitions (larger \( r \)) lead to higher correctness rates at receivers, the overhead created increases considerably faster.

However, independently of the overhead, the second hypothesis is proven to be corrected.

**IV. ERASURE CODING IMPROVES EFFICIENCY**

Coding is a technique that can be use to optimize how redundancy is used. Instead of simply rebroadcasting copies of previously sent frames, packets carry special combinations of parts of the whole information to be disseminate. The idea is that receiving only a subset of all packets sent is enough to decode them into the complete original data transmitted.

Although the decoding process at receivers incurs into computational overhead, this technique tries to optimize the use of redundancy in the data flow. This optimization happens based on two concepts: fragmented redundancy and burst lost prevention. By simply replicating packets at the source, the number of packets sent is the result of a multiplication by an integer number (number of times individual packets are sent). However, using coding techniques, it is possible to have a fragmented number of redundant packets. Differently from simple replication of data, packets sent through coding contain pieces of information from many parts of the source data. For this reason, if there is path break, a specific sequential part of the original data is not lost as it would be if packets were simple replications.

Rateless Erasure Coding [5] is a mechanism that encodes the original data through XOR operations between segments of it. The original data is divided into \( n \) segments which can be combined as any of the \( 2^{n} - 1 \) possible non-empty sets of segments. The degree \( d \) of an encoded packet is the number of segments used to create such packet. The choice of each packet’s \( d \) follows a distribution that aims at optimizing the process. Once the degree is determined, \( d \) out of the \( k \) segments are randomly chosen through a uniform distribution.

The resulted coded data is encapsulated in a package containing also information used to determine the indices of the original data segments used. Whenever a vehicle receives an encoded data it uses previously received data to start decoding its content. The optimum scenario would be one where with any \( n \) encoded packets received, all original data could be decoded. The goal for most Erasure Coding mechanism is to get as close as possible to this optimum.

LT-Code [6] is a Rateless Erasure Coding mechanism that follows a specific distribution, namely Robust Soliton distribution, to determine the degrees \( d \) of the outgoing packets at the source. By this manner, it is possible, with a probability of \( 1 – \delta \), for receivers to obtain the original data upon the reception of \( n + O(\sqrt{n} \ln^2 (n/\delta)) \) encoded packets.

However, when a video is divided into smaller portions of data and then broken into segments\(^2\), it can occur that, at some receivers, not enough packets are received. In this way, the encoded data cannot be decoded and it cannot be used to reproduce the video. Another issue is that part of the payload in each packet has to be used to transport indices.

Despite these disadvantages, our third hypothesis is:

**Hypothesis 3:** Rateless Erasure Coding increases the efficiency on the use of redundancy in VANETs.

**Empirical Evaluation and Results**

As the previous two sections, we have used the Network Simulator 2 to evaluate our premisses in a highway scenario. We have divided the video data file into 200,000 bytes sections and each section has its own encoding process. For the indices, we have separate 200 bytes out of the 1,000 bytes maximum size of the payload. This means that the number of segments in each encoding \( n \) is of 250. We used each byte of the space separate for indices to represent one index, thus, whenever a encoded data has a degree of more than 200, it is discarded.

There are a few parameters that determine how many packets are created for each of the 200,000 bytes sections. We have analyzed them but due to the lack of space we have only show the impact of the most influential. This parameter is the expected number of encoded segments in the buffer at the encoding node (the source camera in this article). The importance of this is that during the encoding process, packets are added and removed from this buffer and the process finishes whenever this buffer is empty. As larger the value of \( R \) is, more encoded packets are sent, thus, more reliable the whole process is.

Besides that, we have also added a parameter \( r \) which is a constant that multiplies the number of packets to be sent. Therefore, if the encoding process ends, other encoded packets are created leading to an additional redundancy. Therefore, we have evaluated different instances of our lt-code based protocol with different configurations of \((R, r)\).

\(^2\)The portions of data could be for instance a GOP of MPEG videos and segments would be parts of each frame within this GOP.
In Figure 1(e), we can see that for vehicles close to the camera we have achieved results reasonably similar to the ones where the redundancy was based solely on data replication with no use of any kind of coding. Furthermore, we notice that as we evaluate the performance of vehicles at greater distances from the camera, the decline in correctness is steep with values close to zero at distances greater than 3000m. Once again, we can verify that the configurations that have better overall average correctness have a worse or equal result for vehicles close to the camera.

The overhead is evaluate in Figure 1(f) comparing the total number of packets sent by each configuration. As the previous solutions, the number of packets sent grows exponentially with increases on the Gossiping probability $p$. Besides that, we can observe that increases on either $R$ or $r$ incur into a proportional and linear grown on the overhead.

The steep decline of performance in terms of correctness at vehicles more distant to the source camera was an unexpected result. We have looked into this and what we have observed is that this is caused by an excessive number of encoded packets at these farther nodes that could not be decoded. With Erasure Coding, it is necessary to receive a minimum amount of 1-degree packets (i.e. packets with the original data) and a reasonable amount of other low degrees packets. Additionally, since 20% of the payload space is occupied by indices instead of video data influences in how much of the original data is collected upon the reception of each packet.

Comparing the performance of the approach using Erasure Coding and without it, we cannot affirm that coding enhances the overall efficiency of redundancy. For vehicles closer to the source camera, the correctness rates achieved are similar with the coding approach incurring into a slightly smaller overhead. However, when we consider farther vehicles, the performance using erasure coding is outperformed by the regular redundancy approach.

For these reasons, our third hypothesis has showed to be erroneous, thus, a fallacy.

V. RELATED WORK

There are some works on data dissemination in VANETs in the literature but they have a substantially different perspective. In [7], the authors discuss dissemination techniques but for the exchange of messages containing either traffic conditions or particular information of vehicles, thus, focusing in a scenario where the information shared is not as large (in terms of bytes) as a video. Besides that, every node in the network is not only an interested party but also a potential source of data. In [8], the authors also focus on the application of informing vehicles of the traffic conditions in their surroundings. Dornbush et al. propose a mechanism for vehicles to estimate traffic conditions and, through a clustering approach, disseminate the obtained information to vehicles in the network.

There are also some analysis on the use of coding in VANETs. In [9], the authors discuss the use of Network Coding in sharing files within a VANET and, in another work [10], they also study the use of the same technique for video streaming in VANETs. However, in both works, the authors focus in a scenario where all vehicles are connected (i.e. a single platoon) and, furthermore, it is not clear whether there are advantages or disadvantages on using coding since the results are too close to each other.

VI. FINAL REMARKS

We have evaluated the impact of redundancy in the dissemination of a video stream in a VANET. We have conducted our analysis through hypotheses tests which gave us an insight on the role of redundancy in video dissemination. We could observe that redundancy improves the performance of dissemination protocols. However, the use of Erasure Coding did not increase redundancy’s effectiveness.

Based on this work, we can observe that although redundancy improves video broadcasting in VANETs, it is not sufficient to make it feasible. The disconnectedness issue could not be handled through simply multiplying the frequency that each particular piece of data referent to the video is transmitted. We have observed that the manipulation of the trade-off between effort (i.e. number of transmissions) and benefit (i.e. successful delivery ratio) is not homogeneous within the network, but rather dependent on localized congestions — increasing the number of repetitions leads to congestion at vehicles close to the camera but increase delivery ratio at farther vehicles.

We plan to continue our study and propose mechanisms that allows vehicles to take local decisions aimed at minimizing collisions and maximizing reachability. Furthermore, we want to evaluate carry-and-forward solutions that handle the issue of disconnection between platoons but incur into delays.

REFERENCES